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RESEARCH MEMORANDUM

ADDITIONAL FATIGUE TESTS ON EFFECTS OF DESIGN DETAILS IN 355-T6 SAND-CAST ALUMINUM ALLOY

By I. D. Eaton and John A. Youra

Aluminum Company of America

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Additional static and fatigue tests were made on aluminum-alloy 355-T6 sand-cast specimens. Direct-stress fatigue tests were made on plate-type specimens with a single 1-inch-diameter as-cast cored hole and on specimens in which the cored hole was reamed to $1\frac{1}{16}$-inch diameter. In addition, direct-stress fatigue tests were made on 0.300-inch-diameter specimens, with various degrees of porosity, machined from the butt ends of plate-type specimens. Comparisons are made with the results of earlier tests, on plate-type specimens with variations in design details such as bosses and ribs, given in NACA Technical Note 2394.

Within the range of stresses used, there were no significant differences in the fatigue strengths of sand-cast specimens with a 1-inch-diameter cored hole when tested with the hole in the as-cast condition or with the hole enlarged 1/16 of an inch in diameter by reaming. When the results of tests on the specimens with a 1-inch-diameter cored hole are compared with results, from the previous investigation, for specimens in which a small cast boss was removed and a 1-inch-diameter hole drilled and reamed in the center of the plate-type specimen there is found to be no significant difference in the results except for a slight difference in the static strengths.

The direct-stress fatigue test results on 0.300-inch-diameter round polished specimens indicate no correlation between the fatigue strengths developed and visual porosity ratings.

INTRODUCTION

In July of 1951 the Aluminum Research Laboratories of the Aluminum Company of America reported in reference 1 direct-stress fatigue test results for plate-type specimens in 355-T6 sand-cast aluminum alloy with variations in design details including bosses, with and without centrally

located holes, and longitudinal and transverse ribs. Following the presentation of the results from this early investigation, some interest was shown in a comparison of the fatigue strengths of the plate-type specimen with a reamed open hole, as used in the initial investigation, with a new specimen in which the open hole was cored and thus had entirely as-cast surfaces. In addition, the question arose as to the effects of various degrees of porosity on the fatigue strength of the plate-type specimens of the initial investigation. Reported herein are results of the additional direct-stress fatigue tests on: (1) a plate-type specimen with cored centrally located hole and (2) 0.300-inch-diameter round polished specimens with various degrees of porosity.

The objects of this investigation were: (1) to compare the static and direct-stress fatigue strengths of plate-type specimens, of 355-T6 aluminum sand-cast alloy, having a centrally located cored hole with the corresponding data from reference 1 for similar specimens with other types of design details such as bosses and ribs; (2) to study the effects of the conditions at the rim of an open hole by comparing the strengths of specimens with: (a) a cored hole (type 1B), (b) a hole in which the cylindrical surface was machined by reaming (type 1B-1) and, (c) a hole in which both the cylindrical surface and a narrow rim on both faces of the specimen were machined (type 1); and (3) to study the effects of porosity on the fatigue strengths of 0.300-inch-diameter specimens taken from the grip ends of the plate-type specimens tested.

This work was done by the Aluminum Company of America and has been made available to the National Advisory Committee for Aeronautics for publication because of its general interest.

MATERIAL AND SPECIMENS

The plate-type fatigue specimen with the 1-inch-diameter cored hole, one of the new specimen types used in this investigation, is shown in figure 1. The second new type was obtained by reaming the cored hole to a diameter of $1\frac{1}{16}$ inches. These specimens were cast at Alcoa's Cleveland Works using the basic pattern previously described in reference 1. The mechanical properties of the 355-T6 aluminum-alloy sand-cast material as determined at Cleveland on separately cast test bars are shown in table I along with the mechanical properties of the material used in preparing the specimens for the earlier tests. The mechanical properties are found to be in good agreement with the average properties for the several lots of material used in the previous investigation. These properties are found to exceed the specified values and are in good agreement with typical values given in reference 2 and are in general agreement with Federal Specifications QQ-A-601a.

As was the case for the specimens in the previous investigation, these specimens were radiographed at the Cleveland Works and only those found to be generally sound were submitted for test. Figure 2 shows the three conditions at the edge of an open hole studied, namely, (1) plain cored hole (type 1B), (2) reamed hole in plate with as-cast surfaces (type 1B-1), and (3) reamed hole, machined surfaces (type 1, boss machined flush with plate previous to reaming hole).

The 0.300-inch-diameter round polished direct-stress fatigue specimens illustrated in figure 3 were machined from the butt ends of the plate-type specimens. Twenty-four specimens were obtained from the butt ends of a specimen which had not been previously tested because of misregistry of the design detail. The location of these specimens is shown in figure 4. Four additional specimens were obtained from each end of several plate-type specimens which had some fatigue test history. In each case, the plate-type specimen had withstood a considerable number of cycles at a low stress (based on the minimum area of the test section) without failure. As can be seen in figure 5, which illustrates the location of the small specimens within the butt ends, specimens A and B were taken from a section of the butt end beyond the keyway through which the load was transferred and thus should not have been subjected to any significant stress cycles during the fatigue testing of the plate-type specimen. Even though the small specimens C and D were taken from portions of the butt end which had been subjected to a cyclic stress, it is believed that the stresses were so small that the behavior of these specimens would show no effect of the previous stress history. As will be seen later, the results for specimens taken from these two locations (specimens C and D) gave fatigue test results which were consistent with the results of specimens taken from nonstressed material (specimens A and B).

PROCEDURE

One static and five fatigue tests were made on specimens of the type shown in figure 1 with a 1-inch-diameter cored hole (type 1B). In addition, three fatigue tests were made on specimens in which the cored hole had been reamed to $1\frac{1}{16}$-inch diameter (type 1B-1). The procedure for the static and fatigue tests on these plate-type specimens has been previously described in reference 1.

Previous to testing, the 0.300-inch-diameter direct-stress fatigue specimens were arranged in order of increasing porosity as evaluated by visual inspection of the machined surfaces. The specimens were divided into five groups in the order of increasing porosity: little, slight, medium, appreciable, and heavy. The degree of porosity for the five classifications is illustrated in figure 6 which shows machined flat coupons also taken from butt ends of the plate-type specimens.

Static testing of the round polished specimens was done in an Amsler Universal Testing machine[1] of the hydraulic type having multiple load ranges from a minimum of 200 pounds to a maximum capacity of 20,000 pounds. The fatigue tests of round polished direct-stress fatigue specimens were made in a Krouse direct tension-compression fatigue testing machine having a maximum capacity of 5,000 pounds. Adaptation of these specimens to the fatigue testing machine was made with the use of fixtures, designed under the direction of Mr. R. L. Templin, which incorporate split rings.

RESULTS

The result of the static test on the cast plate-type specimen with the as-cast cored 1-inch-diameter hole (type 1B) is given in table II. Included in the table for comparisons are the results, taken from reference 1, for the other plate-type specimens. It can be seen that the strength of the specimen with the cored hole is greater than that of the specimen having a reamed hole with machined rims (type 1) but less than that of the plain-plate specimen (type P). The ultimate strength developed by the specimen with a 1-inch cored hole is about 10 percent lower than the tensile strength of the material as determined by tests of separately cast test bars, whereas the strength of the specimen having a reamed hole with machined rims is about 20 percent less than that of the separately cast test bars. The strength of the specimen with the cored hole is greater than the strength of specimens with any of the other design details studied in reference 1.

The results of the fatigue tests on the specimens with the 1-inch-diameter cored hole (type 1B) and the specimens in which the hole was reamed to $1\frac{1}{16}$-inch diameter (type 1B-1) are given in table III. The results have been plotted in figure 7 in which the data are compared with the band of results obtained for the several specimen types reported in reference 1. It can be seen that, except for the difference in the static strengths, there is no significant difference in results obtained for the three specimen types with unreinforced holes. A single curve has been plotted in figure 7 to represent the fatigue test results for the two new specimen types. Included in figure 7 is an average curve, from figure 5(a) of reference 3, for test results on polished round specimens machined from separately cast test bars.

In table IV, the results of tests on sand-cast and wrought aluminum-alloy specimens with unreinforced holes are compared and fatigue strength

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[1]Type 10SZDA, serial number 5068. Periodic calibration of this machine indicates that the error in load reading is less than 1 percent throughout the load range used.

reduction factors, based on round polished specimens, are listed. Included in the table are calculated stress concentration factors, from table XVII of reference 4, for the specimens with holes. It can be seen that for calculated stress concentration factors of 2.5 and 2.7 the range of fatigue strength reduction factors for the castings was only 1.6 to 1.9. Further, for stress concentrations of about the same magnitude in the wrought and sand-cast specimens the sand-cast specimens are considerably less affected by the unreinforced hole than wrought 14S-T6 or 61S-T6 specimens; that is, the fatigue strength reduction factors are lower for the 355-T6 sand castings than for the rolled bar.

The results of static and fatigue tests on 0.300-inch-diameter round polished specimens machined from butt ends of plate-type specimens are given in table V. Included in the table are the porosity ratings based on visual observation of the machined surfaces of the specimens. The results of fatigue tests at zero stress ratio are plotted in figure 8. In this figure, the results have been separated according to the porosity rating of the individual specimens and a band of results is shown which encloses all the test results. Study of these test results shows that no one of the following criteria gives consistently high or low results in the band of results shown: (1) porosity rating, (2) individual plate-type specimens from which the round specimens were obtained, (3) location of specimen within the butt end, or (4) direction of the axis of the round specimen with respect to the longitudinal axis of the plate-type specimen.

It can be seen in figure 8 that there is no correlation between the porosity ratings and fatigue strengths of the specimens. For any of the porosity ratings for which a reasonable number of specimens were tested it can be seen that the results cover the major portion, if not all, of the band of results shown. Further, specimens having the greatest degree of porosity helped to define the upper limit of the band of results and other specimens having a slight porosity rating, which is classed as next to the least porosity, helped to define both the lower and upper limits of the band.

In figure 8, the specimens obtained from the butt ends of the plate-type specimen which had no previous stress history are indicated by solid symbols. It can be seen that the results of these specimens extend from the lower limit of the band of results at low numbers of cycles to failure to the high limit of the band of results at the large number of cycles to failure. A band of results for this series of specimens alone would cover about 75 percent of the band of results for the entire series of specimens tested. Therefore, it would appear that the previous stress history had no significant, if any, effect on the fatigue test results obtained. Included in figure 8 is a replot of the curve for round specimens machined from separately cast test bars. For the range of cycles for which the curve is defined by data, the solid-line portion of the

curve, the results compare favorably with the results for specimens taken from the butt ends of the plate-type specimens.

The results of a few tests on round polished specimens made at stress ratios of -0.5 and -1.0 are included in table V.[2] These results are plotted in figure 9 in which the data points are superimposed on the band of results from figure 8 for tests made at a stress ratio equal to zero. It can be seen that the results for the -0.5 and -1.0 stress ratios with but two exceptions fall within the band of results obtained for the entire group of specimens tested. Insufficient specimens have been tested at the negative stress ratios to define the relations between the fatigue strengths at 0, -0.5, and -1.0 stress ratios.

The band of results for the 0.300-inch-diameter round polished fatigue specimens is compared with the band of results for the 1/4-inch plate-type specimens with various design details and with the average curve for the plain plate-type specimen in figure 10. It is seen that the band of results for the plate-type specimens is lower than that for the round specimens for large numbers of cycles to failure, while for fatigue lives less than about 10,000 cycles one band covers the other. Further, it can be seen that the average curve for the plain plate-type specimen falls within the band of results obtained for the round specimens in the range from about 4,000 to 400,000 cycles. It is slightly below the band at the high number of cycles to failure and above the band for the low number of cycles to failure.

It can be seen in table III that all the fractures in the plate-type specimens went through the centrally located holes. This was also the case for the specimens of type 1 which had a 1-inch-diameter drilled and reamed hole as reported in reference 1. A typical fatigue fracture is shown in figure 11.

It was originally planned to correlate the fatigue test results of the plate-type specimens reported in reference 1 with respect to the degree of porosity in order to explain some of the scatter in the results. In view of the lack of correlation between fatigue strength and degree of porosity found in the tests reported herein on 0.300-inch-diameter specimens, it is to be expected that the scatter in results of the earlier tests cannot be explained on the basis of porosity but is more likely typical scatter of results to be expected in cast materials.

CONCLUSIONS

From the foregoing data and discussion of the static and direct-stress fatigue tests on aluminum-alloy 355-T6 sand-cast plate-type

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[2] Stress ratio is defined as the ratio of the minimum stress to the maximum stress.

specimens with a single centrally located hole and 0.300-inch-diameter round polished specimens, the following conclusions appear to be warranted:

1. The mechanical properties of the separately cast test bars, representing the new plate-type specimens used in these additional tests, compared favorably with the properties of the material used in the initial phases of this investigation.

2. The ultimate strength of the plate-type specimen with a 1-inch-diameter cored hole (32,460 psi) was about 10 percent higher than that of the plate-type specimen having a hole in which both the cylindrical surface and a narrow rim on both faces of the specimen were machined (29,100 psi).

3. There is little, if any, significant difference in the fatigue strength of plate-type specimens with centrally located holes whether or not the hole is produced by the use of a core during casting, the hole is cored then reamed, or the hole is drilled and reamed into a spot machined by removing a boss.

4. For calculated stress concentration factors of 2.5 and 2.7 the range of fatigue strength reduction factors, for castings with an open hole, was from 1.6 to 1.9.

5. For calculated stress concentrations factors of about the same magnitude, the fatigue strength reduction factors were found to average about one-third lower for cast material than for wrought material.

6. There appears to be no correlation between relatively large differences in surface porosity and the fatigue strengths of 0.300-inch-diameter round polished specimens.

7. The fatigue strengths of plain plate-type specimens with as-cast surfaces fall within the band of results for the 0.300-inch-diameter round polished specimen for numbers of cycles to failure between about 4,000 and 400,000. They are slightly below the band of results for higher numbers of cycles to failure and slightly above the band of results for lower numbers of cycles to failure.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., May 14, 1953.

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TABLE I

MECHANICAL PROPERTIES OF 355-T6 SAND-CAST MATERIAL

[Standard separately cast test bars poured with the fatigue specimens[a]]

Type of fatigue specimen	Heat or lot	Tensile strength, psi	Yield strength (0.2-percent offset), psi	Elongation in 2 in., percent	Brinell hardness number	Results from radiographic examination
1B and 1B-1	C8094A[b]	36,100	26,600	3.0	80	Satisfactory quality
	C8094B[b]	34,900	27,100	2.5	80	Satisfactory quality
	C8094D[b]	35,800	27,300	3.0	81	Satisfactory quality
Av.[b]		35,600	27,000	2.8	80	
P	C1205	36,200	29,300	3.0	94	Superior
1	C1384	36,400	30,200	2.0	90	Uniformly sound
2 and 2A	C1704A	37,000	27,100	3.0	78	Generally sound
	C1704B	36,900	27,200	3.0	77	Generally sound
	C1704C	36,800	27,200	3.0	81	Generally sound
3 and 3A	C1582B	36,500	25,400	3.5	86	Generally sound
	C1582C	36,200	24,500	3.5	88	Generally sound
	C1582D	36,000	25,300	3.5	80	Generally sound
	C1582A	36,600	24,900	3.0	86	Generally sound
	C1582X	33,200	25,000	2.5	81	Generally sound
5	C1962B	35,200	25,800	3.0	81	Generally sound
	C2334	34,800	25,300	2.5	82	Generally sound
6	C2771	33,600	25,100	4.0	75	Generally sound
	C2779	34,700	23,200	4.0	81	Generally sound
Av.		35,720	25,960	3.1	83	
Typical values[c]	--------	35,000	25,000	3.0	80	
Federal spec.[d]	--------	32,000	20,000	2.0	80	

[a]For details of specimen see section 7 of A.S.T.M. specification B26-52T, Book 2 of A.S.T.M. Standards, 1952.
[b]Results for lot of material used for additional test specimens, unless otherwise noted all others from table I, ref. 1.
[c]Values from table 21 of ref. 2.
[d]Mechanical property requirements given in table II of Federal Specification QQ-A-601a, U.S. Government Printing Office, Feb. 3, 1950.

TABLE II

RESULTS OF STATIC TESTS ON SAND-CAST PLATE-TYPE SPECIMENS

OF 355-T6 ALUMINUM ALLOY

Specimen type	Description	Plate type		Separately cast test bars			
		Ultimate load, lb	Tensile strength,[a] psi	Tensile strength, psi	Yield strength (0.2-percent offset), psi	Elongation in 2 in., percent	Stress concentration factor[b]
1B[c]	Unreinforced cored 1-in.-diam. hole	57,500	32,460	35,600	27,000	2.8	1.10
P	Plain	62,000	35,200	36,200	29,300	3.0	1.03
1	Unreinforced reamed 1-in.- diam. hole	45,300	29,100	36,400	30,200	2.0	1.25
2	Boss with large fillet	59,750	29,000	36,900	27,200	3.0	1.27
2A	Same as type 2 with hole in boss	59,500	28,700	36,900	27,200	3.0	1.29
3	Boss with small fillet	59,200	30,000	36,300	25,000	3.4	1.21
3A	Same as type 3 with hole in boss	60,000	30,550	36,300	25,000	3.4	1.19
5	Transverse rib	60,700	27,600	35,000	25,500	2.8	1.27
6	Longitudinal rib	60,700	26,200	34,100	23,200	4.0	1.30

[a]Based on net area of rectangular cross section; for types 2 to 6 inclusive, section taken at edge of boss or rib.

[b]Stress concentration factor equals ratio of tensile strength of separately cast test bars to that of plate-type specimen.

[c]Additional specimen type; all others reported in ref. 1.

TABLE III

STATIC AND FATIGUE TEST RESULTS OF 355-T6 ALUMINUM-ALLOY SAND-CAST PLATE

SPECIMENS HAVING AN UNREINFORCED HOLE AT CENTER OF TEST SECTION

Specimen	Actual load condition, lb		Nominal maximum load,[a] lb	Nominal stress,[b] P/A, psi		Cycles to failure	Location of failure
	Minimum	Maximum		Minimum	Maximum		
Type 1B specimens having 1-in.-diam. cored hole							
D-3	0	57,500	57,500	0	32,460	Static	
D-1	-15	35,515	35,530	0	28,920	464	
A-1	-55	35,485	36,540	0	19,580	14,400	Through central hole
A-2	170	21,800	21,630	0	11,930	206,300	no failure; removed
A-3	120	12,580	12,460	0	6,900	3,435,100	
D-4	15	9,155	9,140	0	5,160	26,182,900	
Type 1B-1 specimens having a cored hole reamed to $1\frac{1}{16}$-in. diam.							
B-3	40	35,770	35,730	0	20,450	10,300	Through central hole
B-2	0	27,800	27,800	0	14,970	65,700	
D-2	30	13,910	13,880	0	7,910	2,229,000	

[a]Based on actual load range and zero minimum load.

[b]Calculated stress at minimum section based on load range and measured dimensions of individual specimens.

TABLE IV

COMPARISON OF FATIGUE STRENGTHS FOR PLATE-TYPE SPECIMENS OF WROUGHT AND CAST MATERIALS

$$\left[\text{Stress ratio} = \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0\right]$$

Plate material	Specimen type[a]	Stress concentration factor[b]	Number of cycles					Material description
			10^5	5×10^5	10^6	2×10^6	10^7	
Tensile stress at failure, psi								
14S-T6[c]	Round	---	47,500	42,200	40,400	38,900	35,900	Rolled rectangular bar, 1 by $7\frac{1}{2}$ in.
14S-T6[c]	GX	---	18,700	14,600	13,700	12,900	11,800	
61S-T6[c]	Round	---	36,000	31,700	30,200	28,900	26,000	Rolled rectangular bar, 1 by $7\frac{1}{2}$ in.
61S-T6[c]	GX	---	17,600	13,600	12,400	11,600	10,000	
355-T6	Round	---	[d]25,000	16,900	14,900	13,000	10,700	Separately cast test bars
355-T6	1	---	13,650	9,100	7,900	6,900	5,600	cast plate
355-T6	1B and 1B-1	---	14,000	10,000	8,800	7,700	6,300	
Fatigue strength reduction factor[e]								
14S-T6	GX	2.8	2.5	2.9	2.9	3.0	3.0	Rolled rectangular bar, 1 by $7\frac{1}{2}$ in.
61S-T6	GX	2.8	2.0	2.3	2.4	2.5	2.6	
355-T6	1	2.7	1.7	1.9	1.9	1.9	1.9	Cast plate
355-T6	1B	2.7	1.6	1.7	1.7	1.7	1.7	
355-T6	1B-1	2.5	1.6	1.7	1.7	1.7	1.7	

[a]Round: round polished specimen

GX: test section 9 by $7\frac{1}{2}$ by 1/4 in., single reamed centrally located hole (41/64-in. diam.)

1: test section $8\frac{1}{4}$ by 8 by 1/4 in., single reamed centrally located open hole (1-in. diam.)

1B: test section $8\frac{1}{4}$ by 8 by 1/4 in., single cored centrally located open hole (1-in. diam.)

1B-1: test section $8\frac{1}{4}$ by 8 by 1/4 in., single reamed centrally located open hole $\left(1\frac{1}{16}\text{-in. diam.}\right)$

[b]Calculated stress concentration factor from table XVIII of ref. 4.

[c]Unpublished results.

[d]Extrapolated value.

[e]Fatigue strength reduction factor equals ratio of fatigue strength of round polished specimen to fatigue strength of specimen with open hole.

TABLE V

STATIC AND FATIGUE TEST RESULTS OF SMALL ROUND POLISHED SPECIMENS

MACHINED FROM BUTT ENDS OF PLATE-TYPE SPECIMENS

[Diam. of test section, 0.300 in.]

Specimen	Classification of porosity	Direction of specimen[a]	Actual load range, lb		Nominal stress range, psi		Cycles to failure[b]
			Minimum	Maximum	Minimum	Maximum	
Specimens machined from butt ends of type 3 specimen C1582-D7; no previous stress history; stress ratio, 0							
C1582-D7-4	Slight	Trans.	0	2,210	0	31,570	Static
-9	Slight	Long.	0	1,950	0	27,850	Static
-15	Slight	Trans.	0	2,120	0	30,200	Static
-20	Slight	Long.	0	1,940	0	27,620	Static
-1	Slight	Trans.	5	840	0	11,860	1,944,700
-3	Slight	Trans.	10	700	0	9,840	3,758,500
-5	Slight	Trans.	0	1,185	0	16,800	70,500
-7	Slight	Trans.	0	610	0	8,680	7,720,600
-13	Slight	Trans.	0	1,655	0	23,820	7,100
-16	Slight	Trans.	-5	490	0	7,030	101,334,800
-8	Slight	Trans.	5	980	0	13,830	502,300
-10	Slight	Long.	-5	820	0	11,700	2,564,000
-11	Slight	Long.	5	700	0	10,000	29,225,000
-17	Slight	Long.	10	1,120	0	15,780	401,400
-19	Slight	Long.	5	1,395	0	19,950	67,100
-23	Slight	Long.	-5	1,675	0	24,000	7,000
Specimens machined from butt ends of type 3 specimen C1582-D7; no previous history; stress ratio, -0.5							
C1582-D7-2	Slight	Trans.	-420	840	-5,980	11,960	543,000
-6	Slight	Trans.	-625	1,250	-8,960	17,920	196,500
-14	Slight	Trans.	-835	1,670	-11,975	23,950	3,100
-18	Slight	Long.	-695	1,390	-9,910	19,820	102,600
-22	Slight	Long.	-280	560	-3,995	7,990	8,420,500
Specimens machined from butt ends of type 3 specimen C1582-D7; no previous history; stress ratio, -1.0							
C1582-D7-12	Slight	Long.	-710	710	-10,060	10,060	1,599,600
-24	Slight	Long.	-1,740	1,740	-24,850	24,850	3,500
Specimens machined from butt end of type 3A specimen C1582-B7 tested for 134,627,600 cycles from zero to 6,050 psi in test section; stress ratio, 0							
C1582-B7-A	Medium	Trans.	0	1,535	0	22,000	33,400
-A1	Medium	Trans.	0	1,115	0	15,950	462,900
-B	Medium	Trans.	0	700	0	10,000	62,331,900
-B1	Little	Trans.	10	1,160	0	15,920	272,500
-C	Slight	Long.	0	1,550	0	22,000	107,500
-C1	Little	Long.	5	1,135	0	16,040	494,500
-D	Slight	Long.	0	1,125	0	16,000	833,800
-D1	Slight	Long.	-5	715	0	10,170	32,542,200
Specimens from butt ends of type 5 specimen C2334-8 tested for 95,503,200 cycles from zero to 5,930 psi in test section; stress ratio, 0							
C2334-8-A	Appreciable	Trans.	10	1,120	0	15,830	397,400
-A1	Slight	Trans.	0	1,540	0	22,060	46,200
-B	Appreciable	Trans.	-5	1,510	0	21,760	18,500
-B1	Appreciable	Trans.	0	840	0	12,000	1,790,000
-C	Heavy	Long.	0	1,540	0	21,880	192,700
-C1	Appreciable	Long.	0	705	0	10,060	5,337,000
-D	Heavy	Long.	0	1,050	0	15,000	835,200
-D1	Heavy	Long.	0	700	0	10,000	10,328,300
Specimens from butt ends of type 6 specimen C2771-7 tested for 68,329,700 cycles from zero to 6,870 psi in test section; stress ratio, 0							
C2771-7-A	Appreciable	Trans.	0	1,125	0	16,000	532,500
-A1	Heavy	Trans.	-5	1,540	0	22,040	30,200
-B	Heavy	Trans.	0	1,115	0	15,940	244,700
-B1	Heavy	Trans.	0	700	0	9,960	8,139,500
-C	Heavy	Long.	5	1,545	0	21,930	66,400
-C1	Heavy	Long.	0	1,120	0	15,940	976,200
-D	Heavy	Long.	0	700	0	10,000	6,754,900
-D1	Heavy	Long.	0	1,330	0	19,000	245,300
Specimens from butt ends of plain-type specimen C1205-F tested for 21,059,000 cycles from zero to 7,310 psi in test section; stress ratio, 0							
C1205-F-A	Slight	Trans.	0	1,130	0	15,990	381,500
-A1	Appreciable	Trans.	10	1,540	0	21,880	90,400
-B	Slight	Trans.	5	710	0	10,000	11,090,400
-B1	Slight	Trans.	0	1,125	0	16,050	229,800
-C	Slight	Long.	10	1,540	0	21,950	193,400
-C1	Slight	Long.	0	1,130	0	16,000	624,400
-D	Slight	Long.	0	700	0	10,070	11,128,000
-D1	Slight	Long.	0	1,550	0	22,000	164,500

[a]With reference to longitudinal center line of plate-type specimen.
[b]All specimens failed.

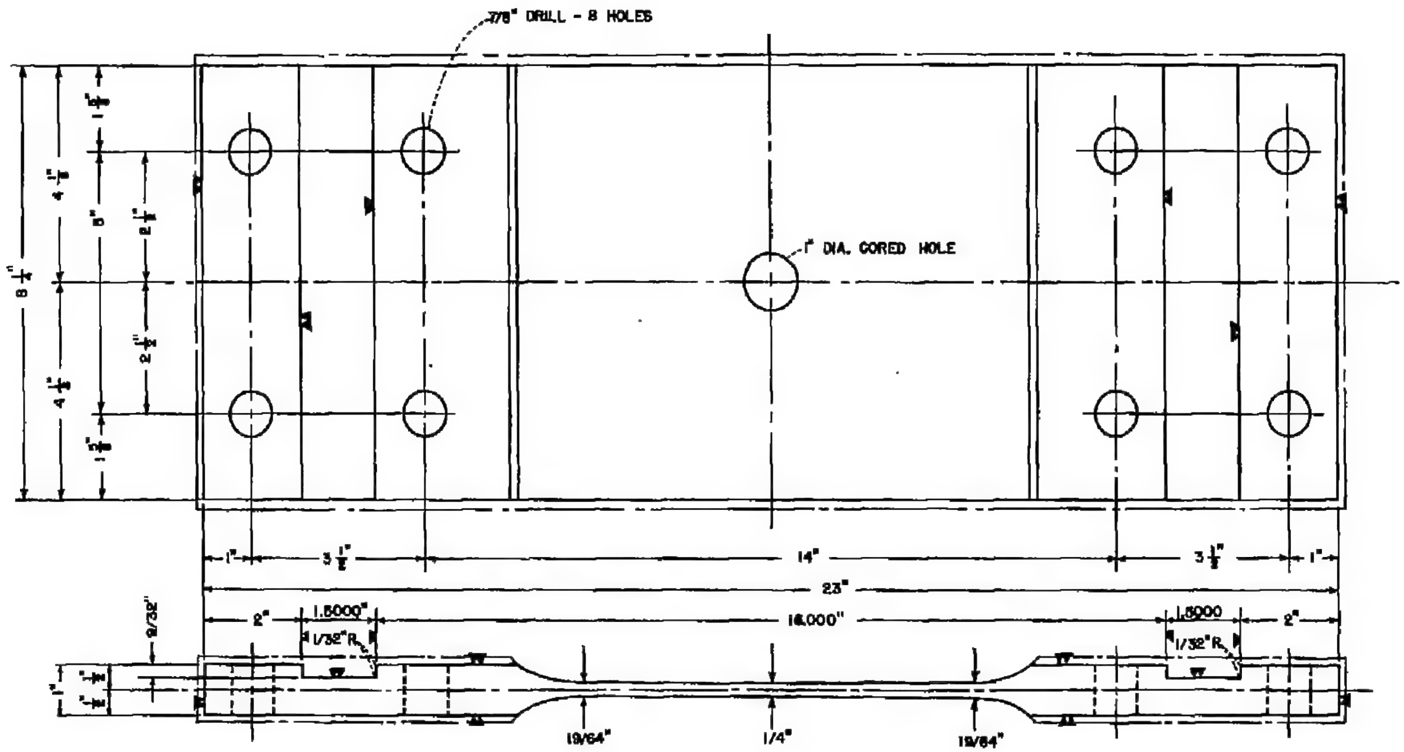

Figure 1.- Plate-type fatigue specimen with 1-inch-diameter cored hole (type 1B). For specimen type 1B-1 hole was reamed to $1\frac{1}{16}$-inch diameter.

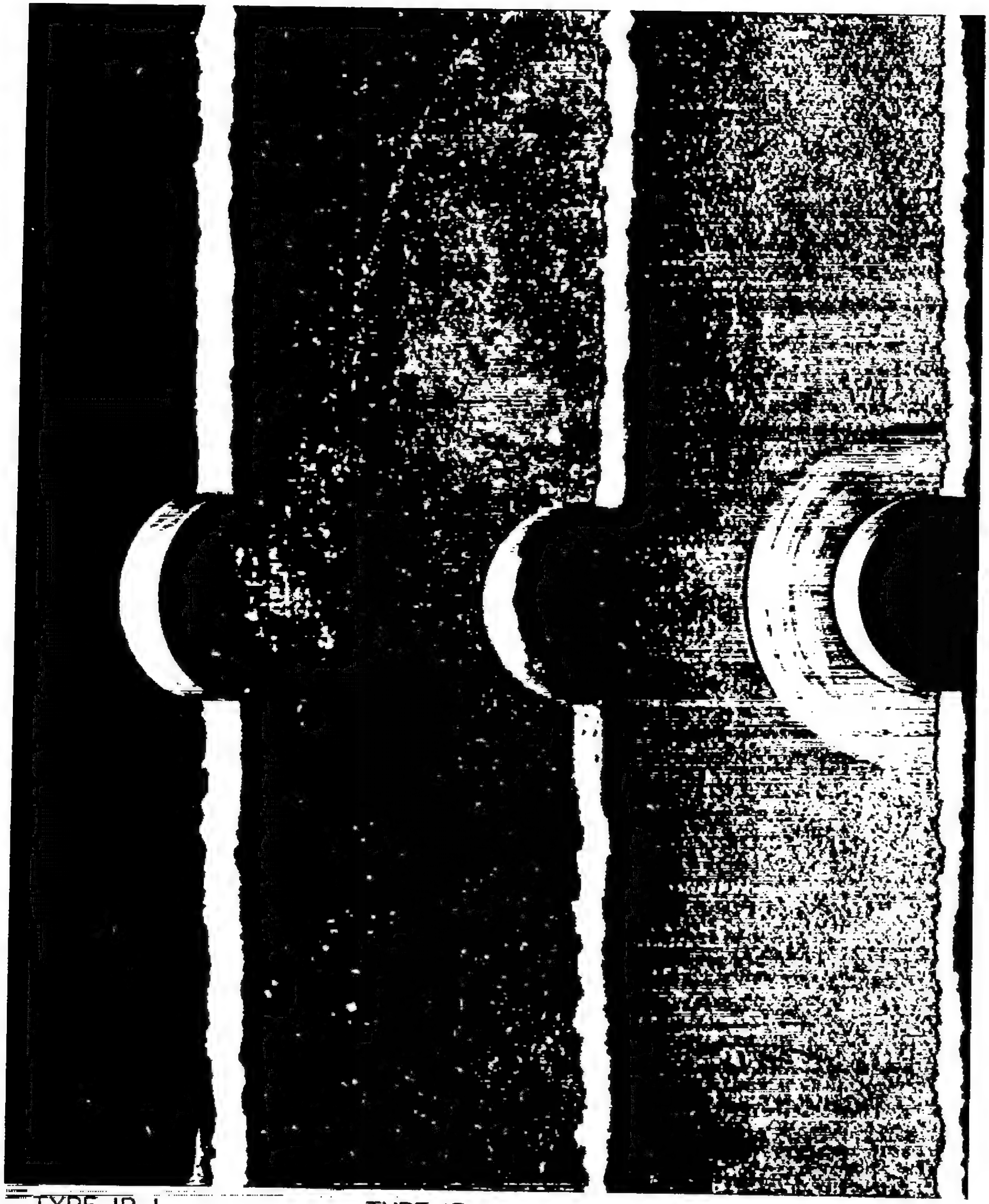

Figure 2.- Conditions of open hole in monobloc sand-cast specimen.

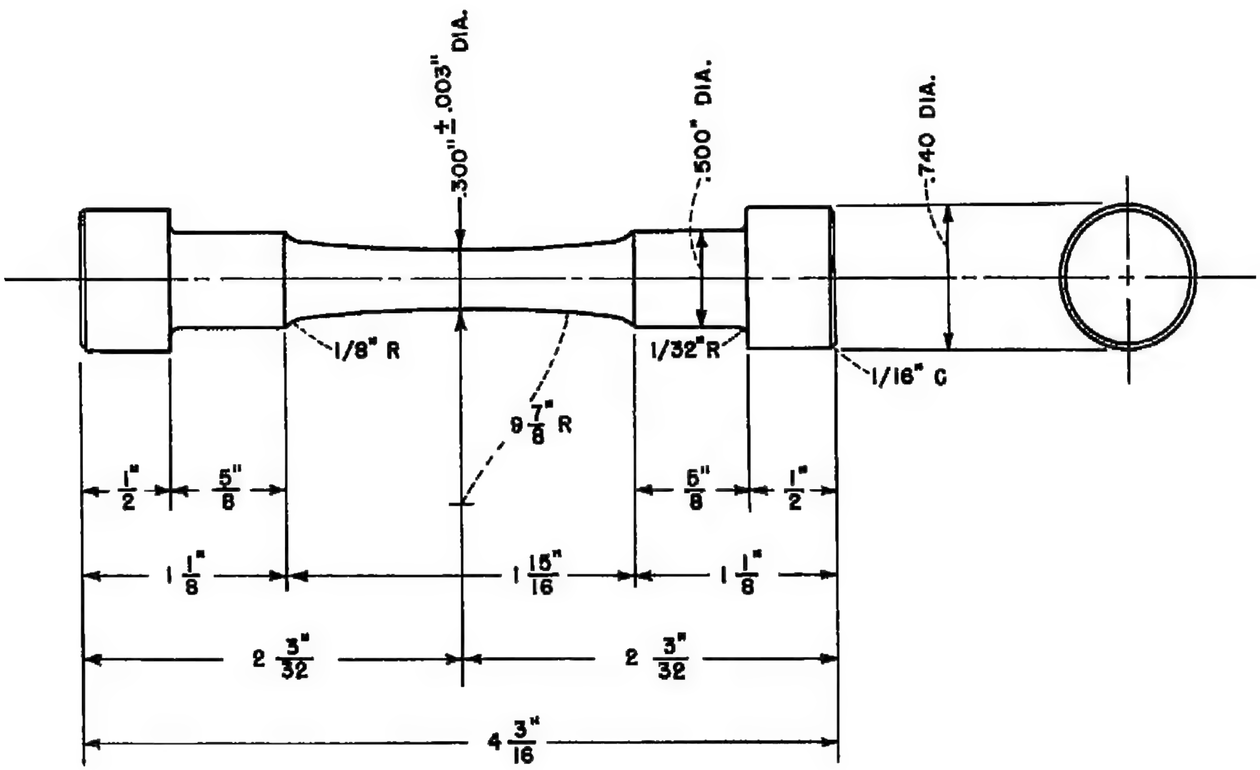

Figure 3.- 0.300-inch-diameter round polished direct-stress fatigue specimen.

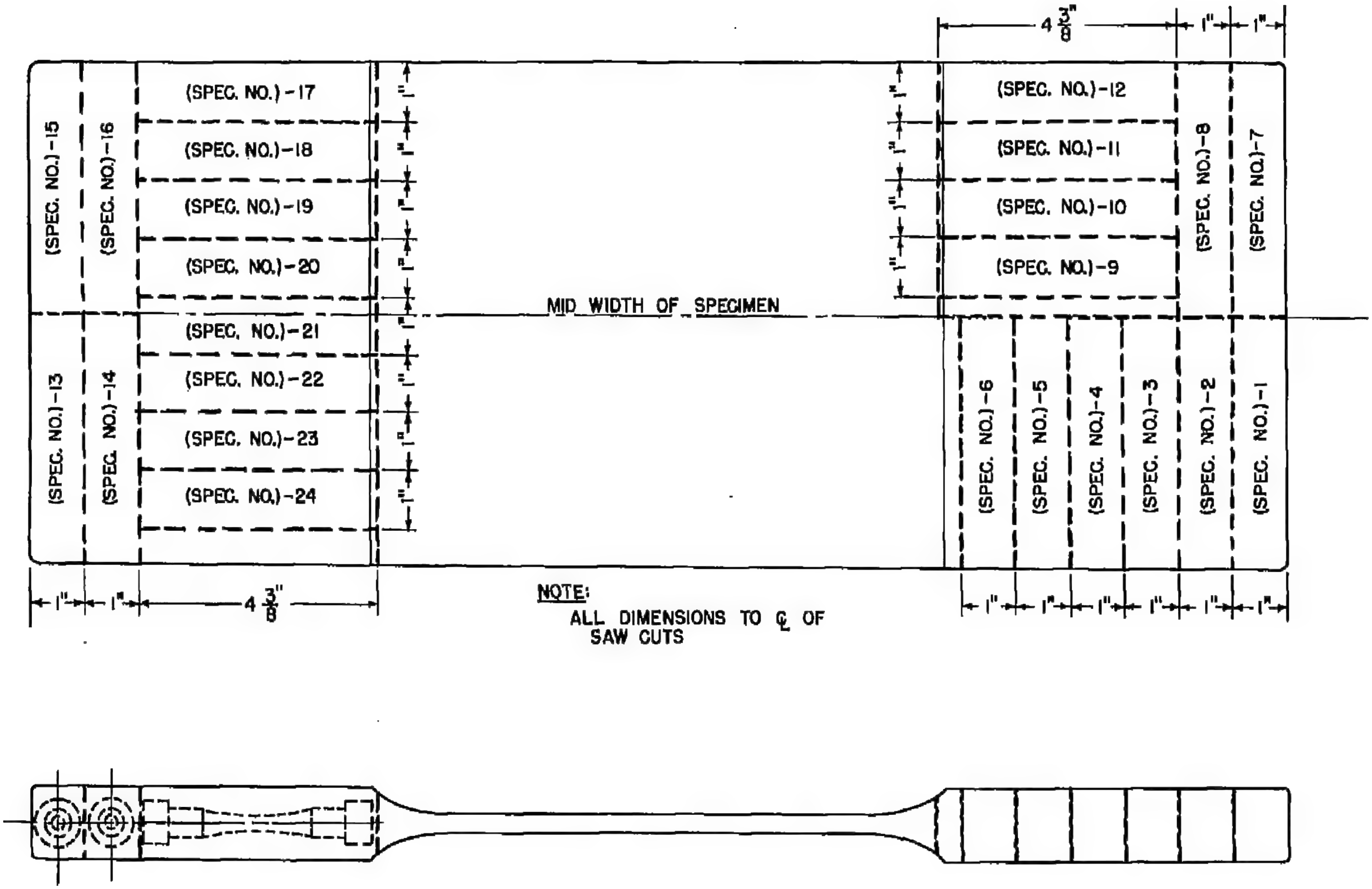

Figure 4.- Location of direct-stress fatigue specimens from casting.

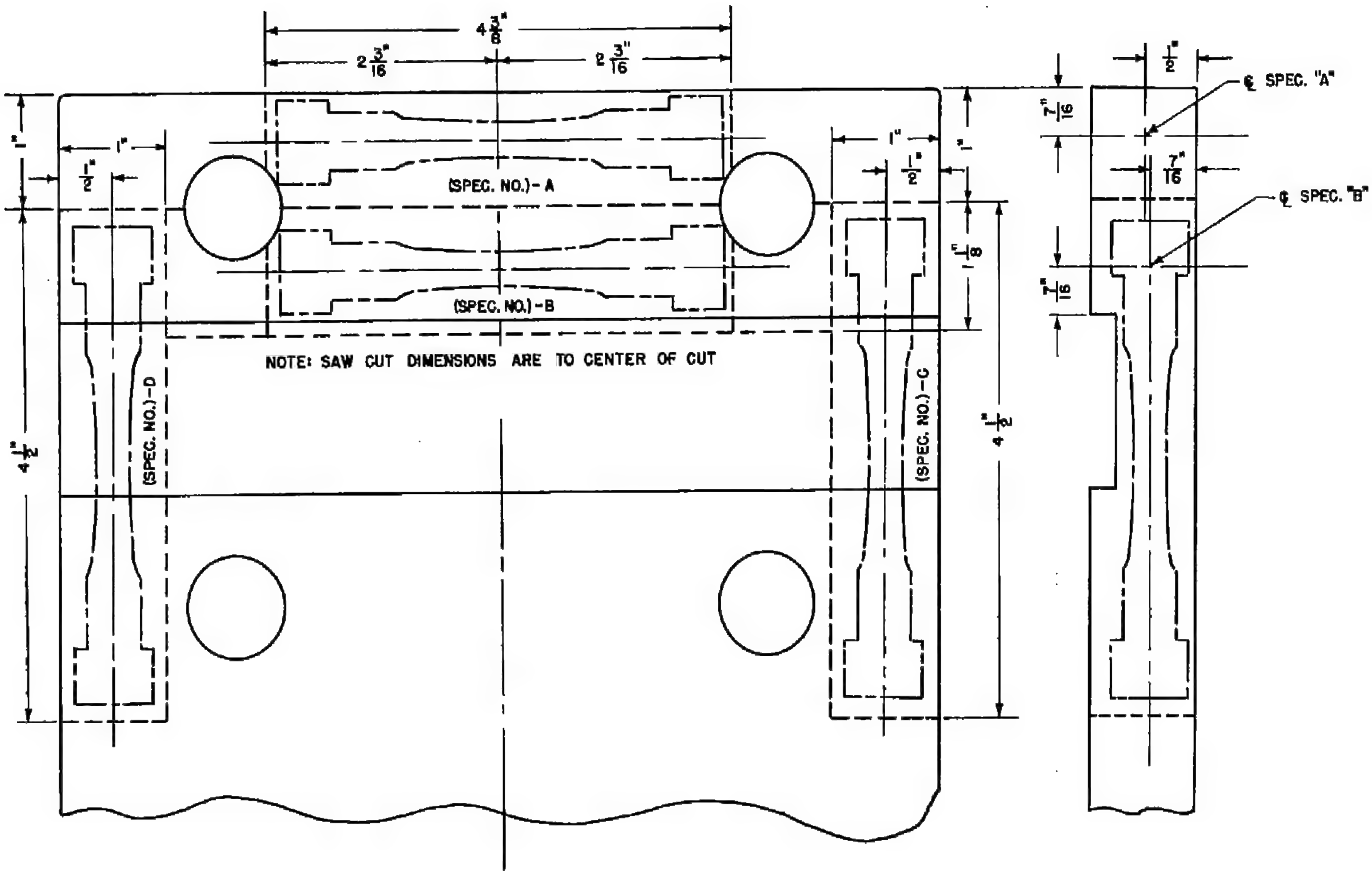

Figure 5.- Location of direct-stress fatigue specimens from machined casting. (Specimen number followed by "-1" indicates it was machined from opposite butt end.)

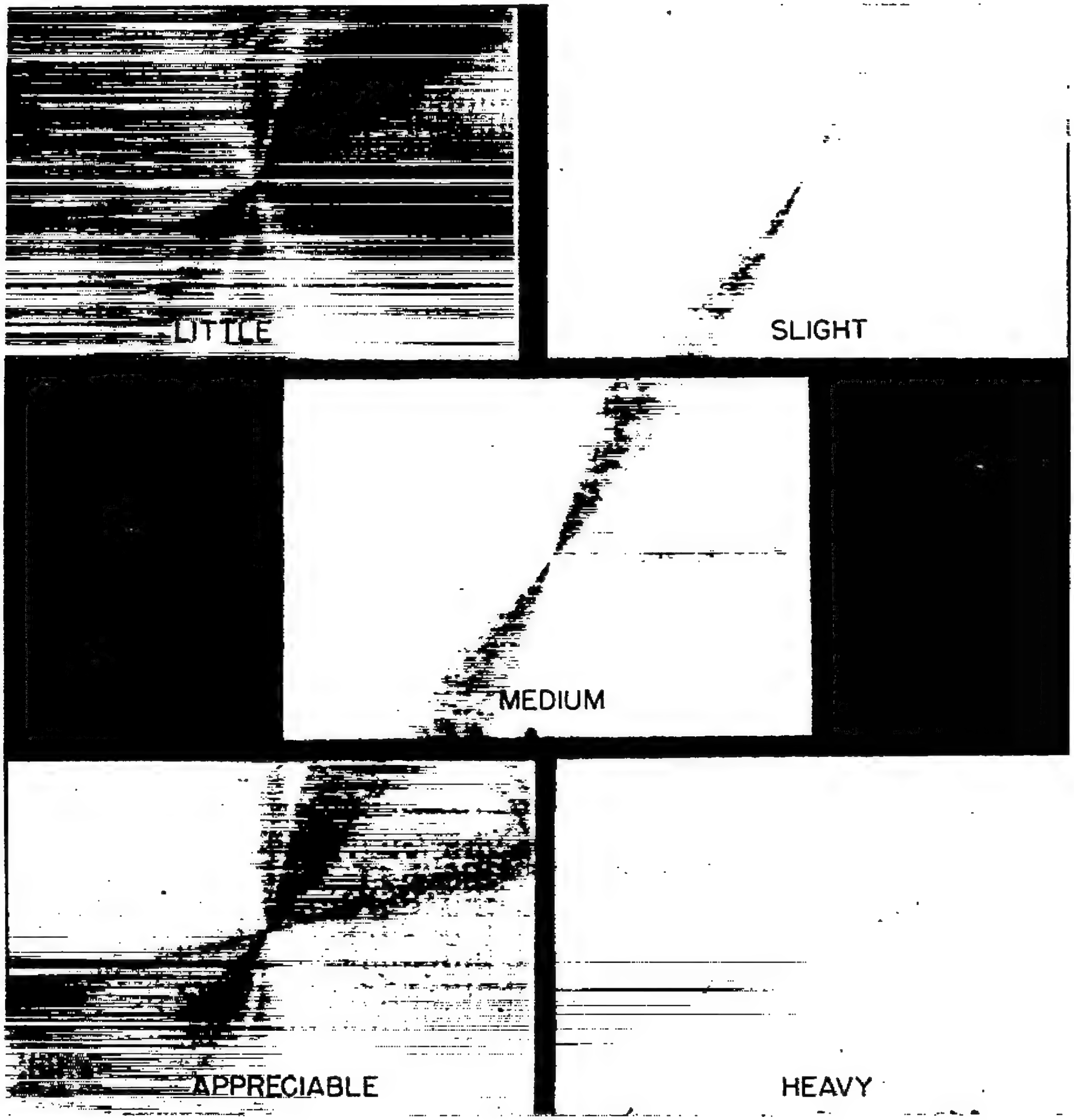

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Figure 6.- Coupons used in grading 0.300-inch-diameter specimens for visual porosity ratings.

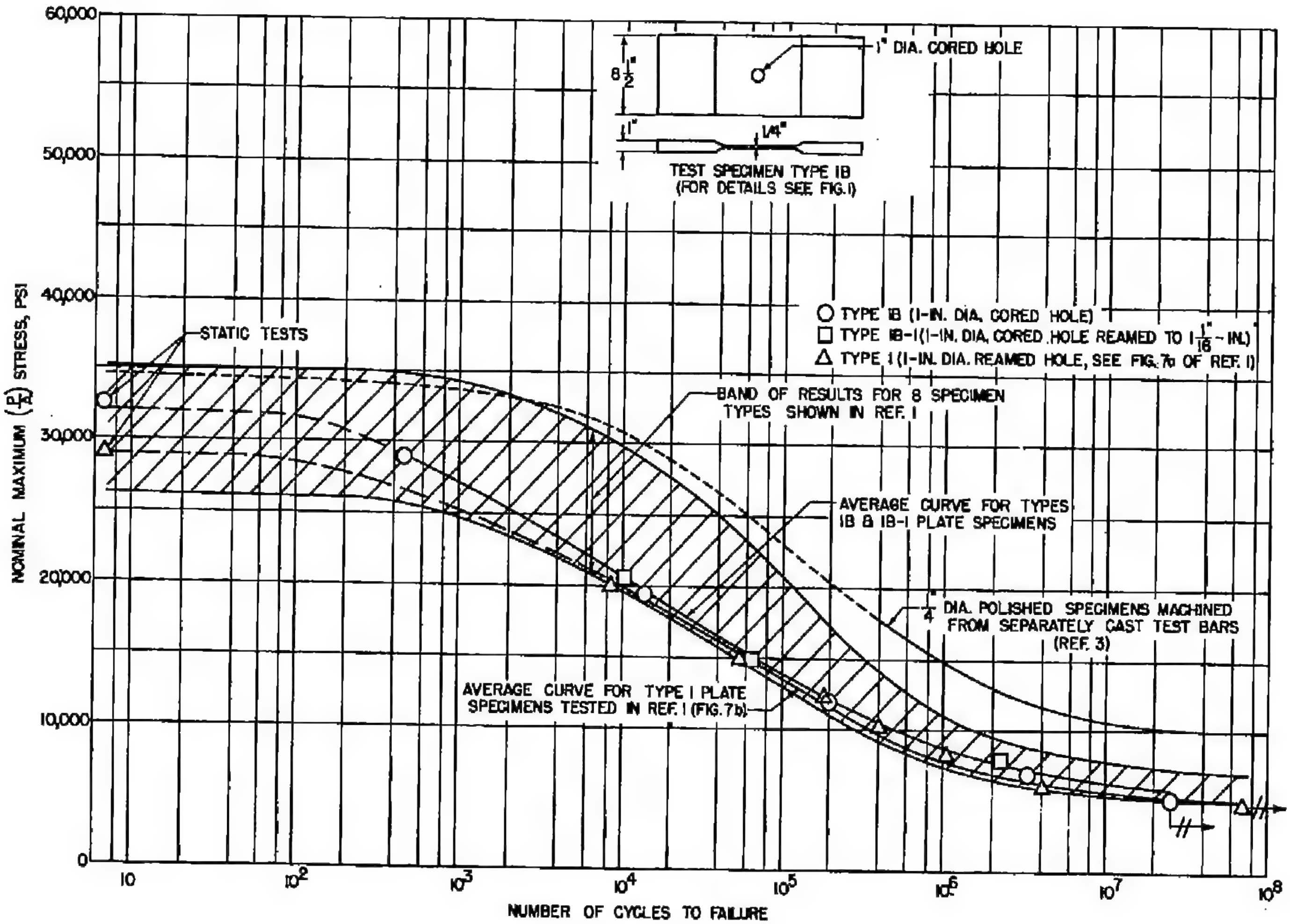

Figure 7.- Direct-stress fatigue test results on 355-T6 aluminum-alloy sand-cast specimens. Plate specimens with single open hole. Stress ratio $= \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0$.

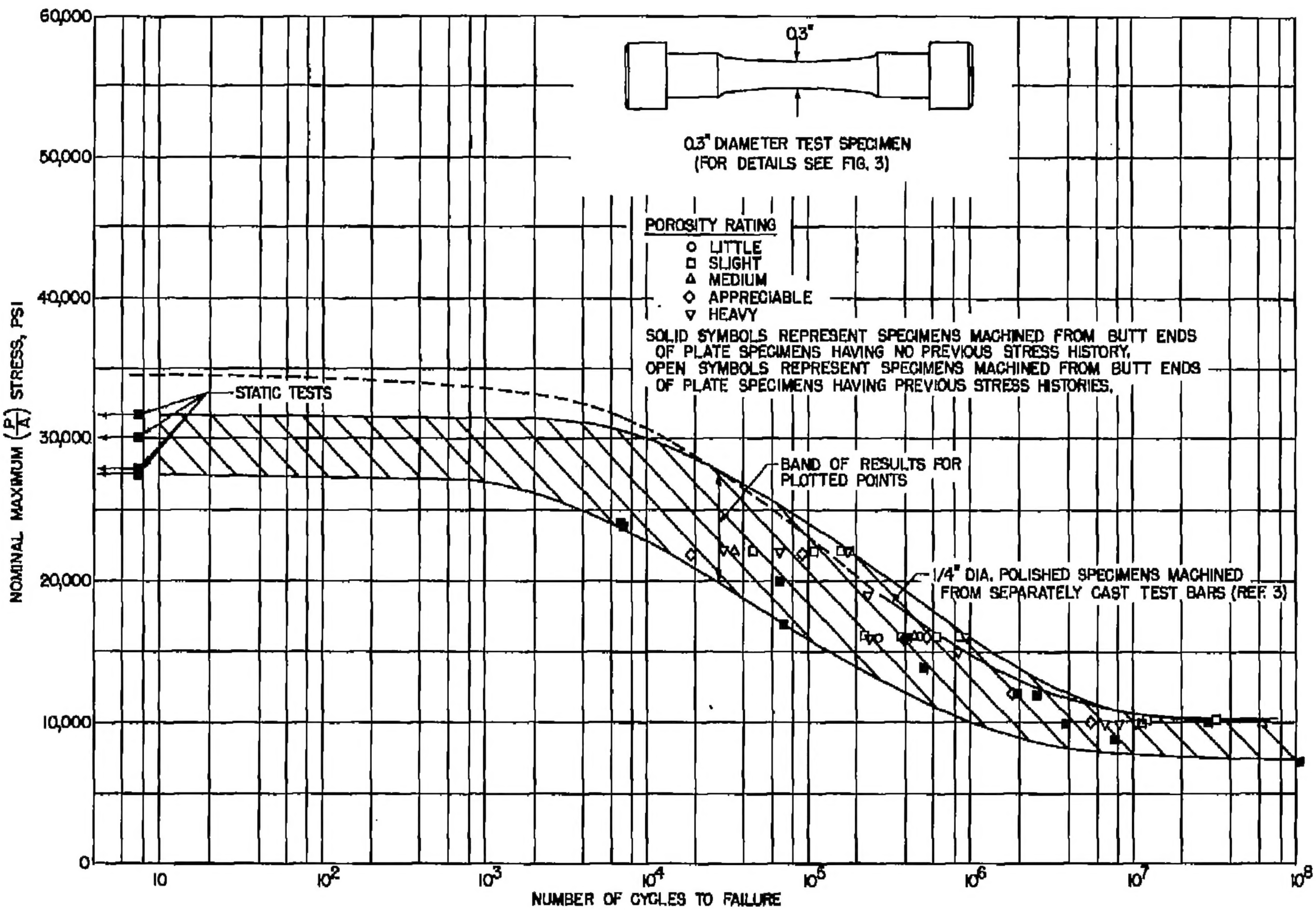

Figure 8.- Direct-stress fatigue test results for 355-T6 sand-cast aluminum alloy. Effects of variation in porosity. Stress ratio = $\frac{\text{Minimum stress}}{\text{Maximum stress}} = 0$.

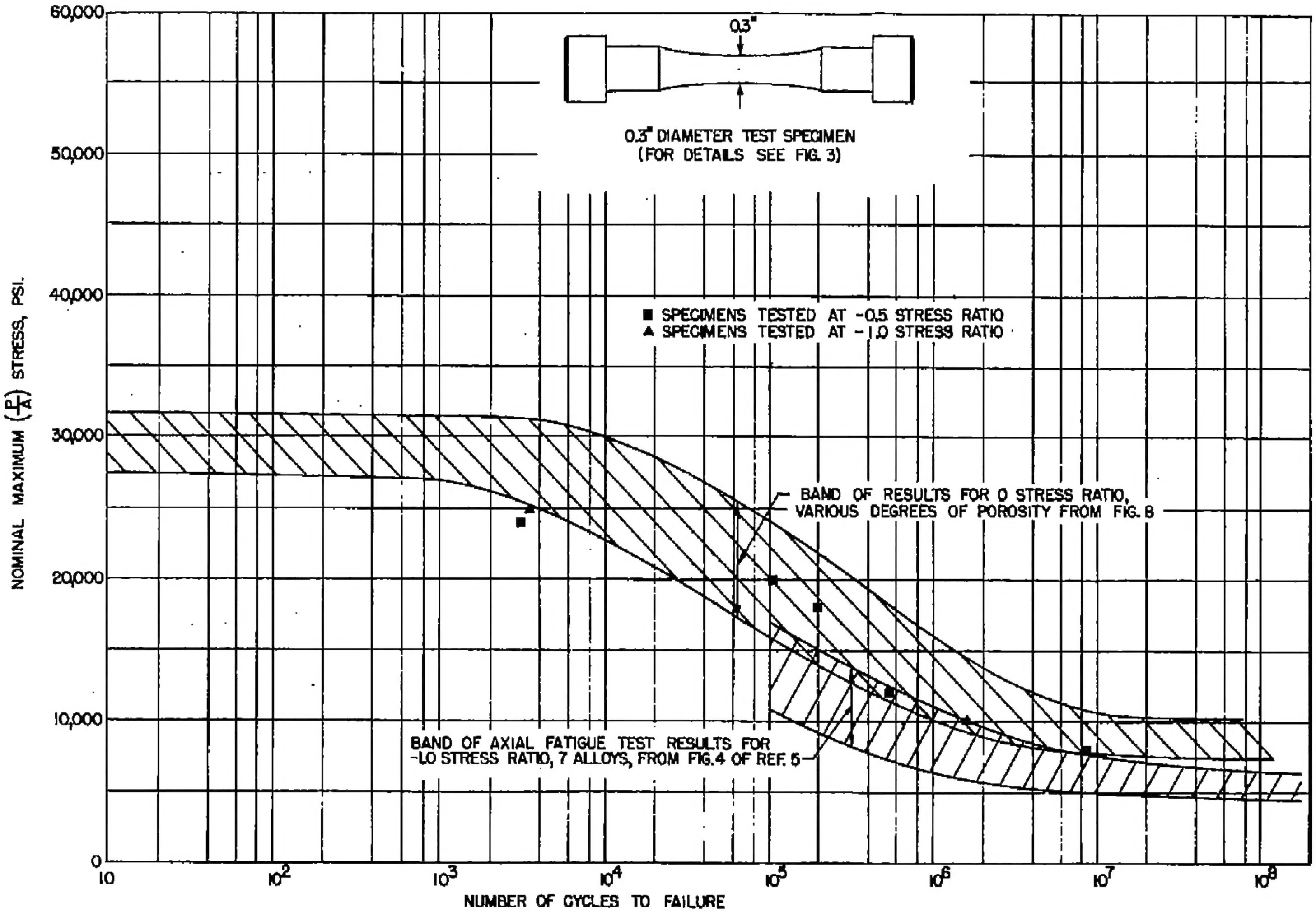

Figure 9.- Direct-stress fatigue test results for 355-T6 sand-cast aluminum alloy. -0.5 and -1.0 stress ratios. Stress ratio = $\frac{\text{Minimum stress}}{\text{Maximum stress}}$.

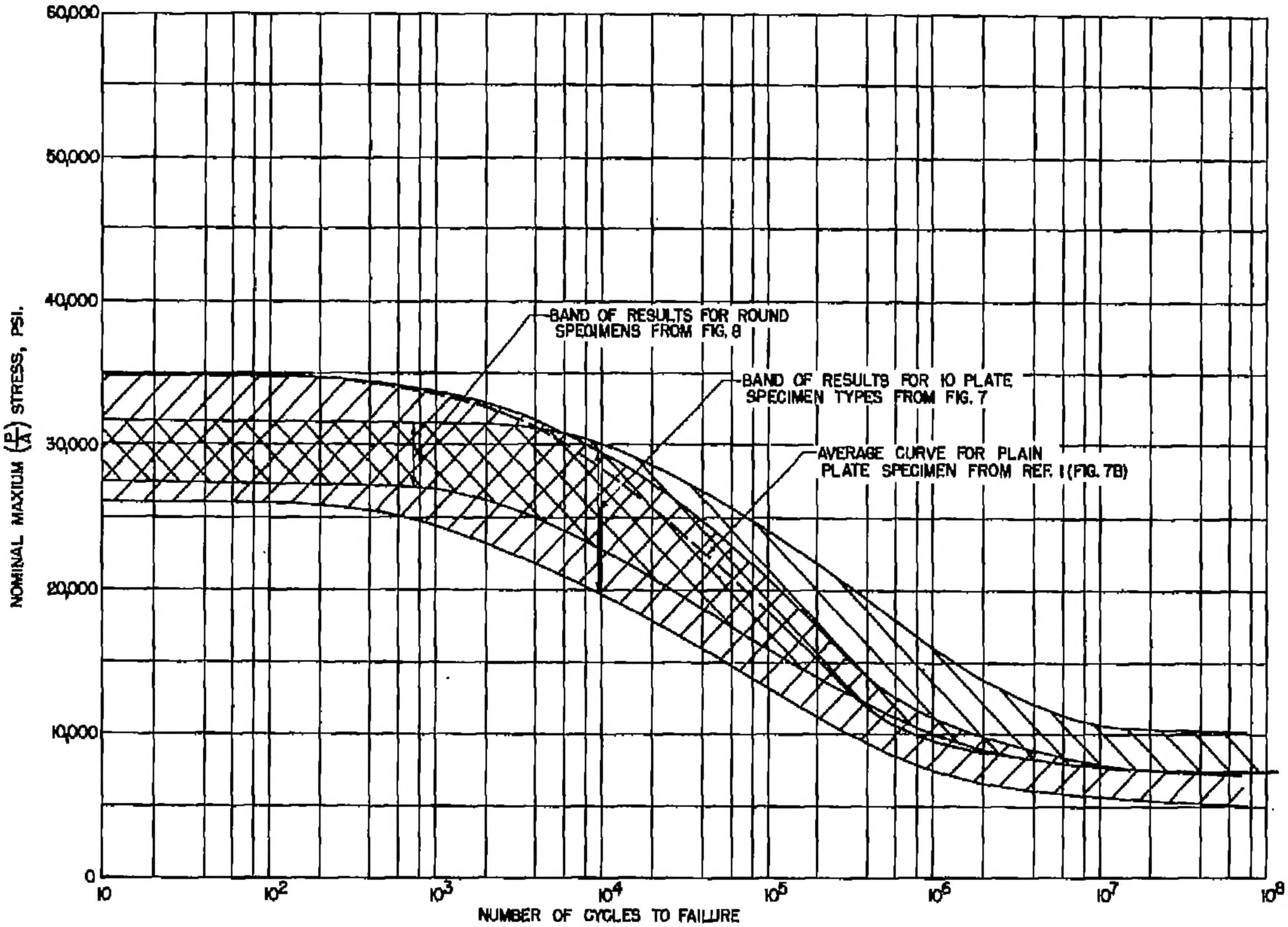

Figure 10.- Comparison of direct-stress fatigue test results for 355-T6 aluminum-alloy sand-castings. As-cast plate-type specimens and machined round specimens.

$$\text{Stress ratio} = \frac{\text{Minimum stress}}{\text{Maximum stress}} = 0.$$

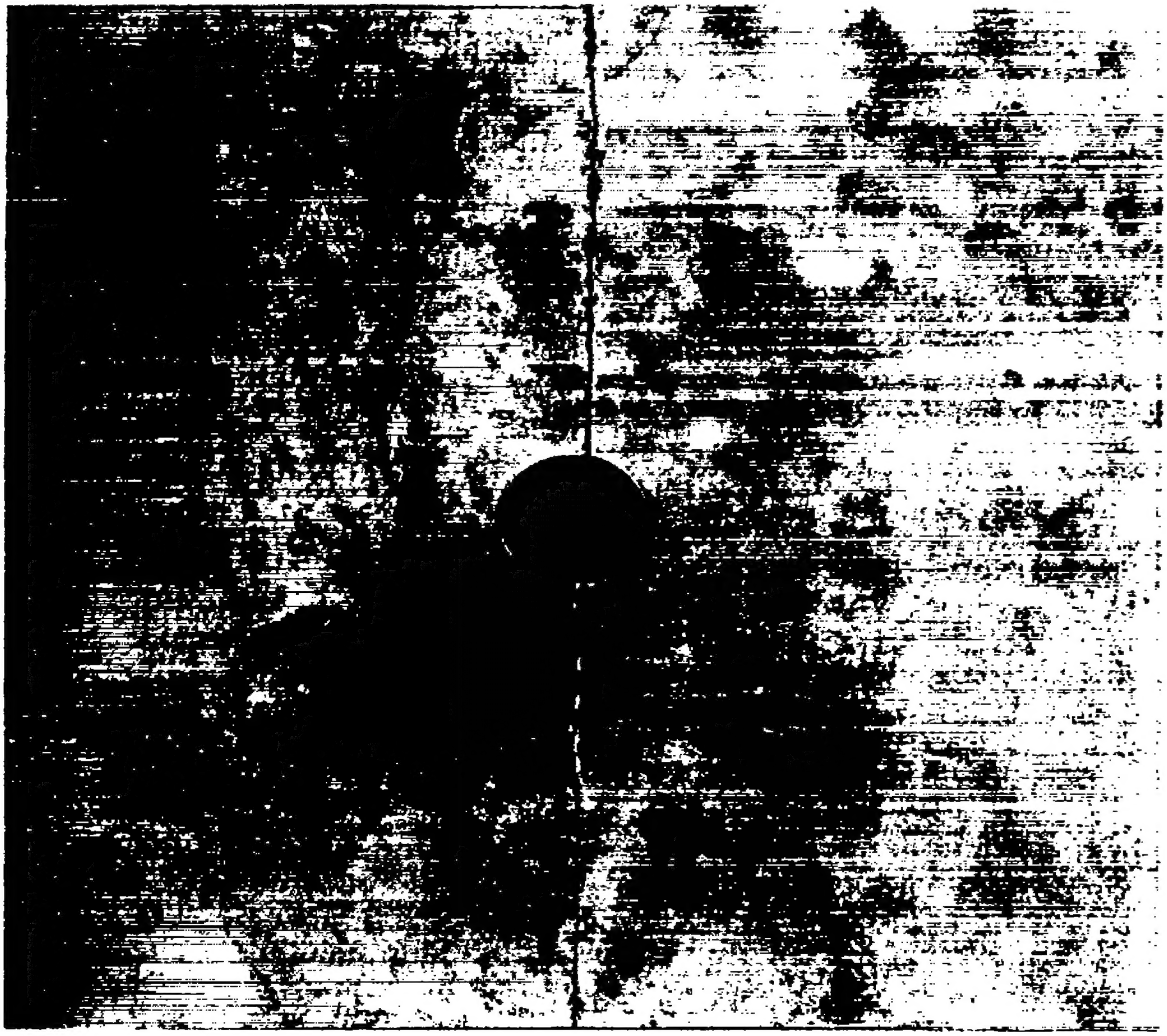

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Figure 11.- Typical fatigue fracture of sand-cast specimen with unreinforced open hole. (As-cast hole shown.)